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Multi-Band Optical Systems to Enable Ultra-High Speed Transmissions

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Current forecasts indicate that the fastest growing IP-traffic is in metro and data center interconnect (DCI) [1]. The exploitation of the entire low-loss spectrum of single-mode fibers (SMF) (from 1260 nm up to 1620 nm) was proposed to avoid the predictable capacity crunch and the eventual need for a new fibre infrastructure roll-out. First analytic result considering multi-band (MB) transmission (from O- to L-band) hint an achievable traffic load exceeding 200 Tb/s for a 500 km link in a single SMF [2].

The maximum transmittable capacity over ITU-T G.652D SMF, which is the mainly deployed fiber type [3], is evaluated in this work. Three different fiber span lengths are considered: 40 km, 60 km and 80 km. A high level overview of the MB setup is depicted in Fig. 1 (left). The system is composed of a MB transmission bench composed of {L, C, S, E, O}-band transmitters. 50 GHz spaced polarization multiplexed (PM)-MQAM signals with root raised cosine shaping (roll-off = 0.15) and a symbol rate of 32 Gbaud are multiplexed and launched into the fiber link. A 2 nm guard-band between adjacent bands is assumed. At the receiver side, the bands are de-multiplexed, amplified and then demodulated. We assume lumped amplifiers: Praseodymium doped fibre amplifier(DFA) in O-band [4], Bismuth DFA in E-band [5], Thulium DFA in S-band [6] and Erbium DFA in C- and L-bands. A noise figure of 6, 5.5, 7, 6 and 7 dB are assumed for {L, C, S, E, O}-band amplifiers, respectively. The wavelength ranges and number of channels in each band are reported in Table 1. The local-optimization global-optimization (LOGO) approach [7] is employed to optimize the launched power. The overall signal-to-noise-ratio (SNR) is estimated considering the impact of non-linear interference (NLI) which is evaluated using the generalized Gaussian noise (GGN) model [8]. The GGN model takes into account the frequency dependence of the fiber loss, the chromatic dispersion and the stimulated Raman scattering (SRS). Finally, the achievable capacity assuming a flexible transceiver capable to completely exploit the available SNR is computed.

Table 1: Per-band system parameters.

Band/Wavelength Range (nm)	L (1565-1625)	C (1530-1565)	S (1460-1530)	E (1360-1460)	O (1260-1360)
Number of channels	136	82	182	295	237

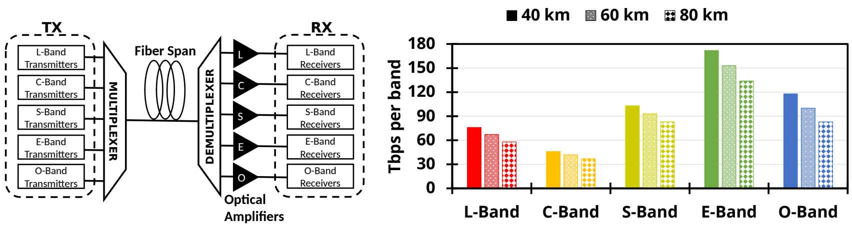

Figure 1: System setup (**left**) and per band (**right**) capacity after transmission along 40 km, 60 km and 80 km of SMF.

The per band capacity illustrated in Fig. 1 (right) shows that C-band provides a low capacity when compared with the remaining bands as a consequence of its narrow bandwidth (see Table 1). On the other hand, the E-band shows the highest capacity mainly due to high channel count ($\sim$300 channels). By observing the evolution of the per band capacity over distance, a higher negative slope is observed for S-, E- and O-bands when compared with the L- and C-bands. This behavior can be explained by analyzing the dominant transmission impairments. Indeed, the worse performance is observed in O-band which is severely degraded by signal depletion. Consequently, amplified spontaneous emission (ASE) noise is the main transmission impairment. On the other hand, L- and C-band transmission is mainly dominated by NLI due to the strong SRS pump from the neighbour bands.

In case of short-reach links ($\leq$ 40 km), the total capacity is $>$ 500 Tb/s/fiberwhich is an enormous increase with respect to current commercial C+L-band systems. Moreover, even for distances around 80 km, the total fiber capacity is still in the order of 400 Tb/s/fiber. C-band represents just a small part of the capacity available in the fiber. Exploiting the remaining low-loss bands increases the potentialities the already deployed optical fiber infrastructure. However, sophisticated techniques are needed to efficiently plan the line system.

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[1] Cisco Visual Networking Index: Forecast and Methodology, June 2017.
[2] J. K. Fischer et al. Maximizing the capacity of installed optical fiber... In *ICTON*, page Tu.B3.3, 2018.
[3] E. Pincemin. Capacity growth through multi-band amplified WDM system. In *ECOC Workshop WS01, 2018*.
[4] Praseodymium fluoride fiber glass doped amplifier, product data sheet. https://www.fiberlabs.com.
[5] E. Dianov. Bismuth-doped optical fibers: ... *Light: Science & Applications*, 1, 2012.
[6] S. Aozasa et al. Tm-doped fiber amplifiers for 1470-nm-band WDM signals. *PTL*, 12(10):1331–1333, 2000.
[7] P. Poggiolini et al. The LOGON strategy for low-complexity control plane... In *OFC*, page OW1H.3, 2013.
[8] M. Cantono et al. On the interplay of nonlinear interference generation with... *IEEE / OSA JLT*, 2018.